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Numerical Reconstruction of Perfectly Conducting Inclusions from One Electrostatic Boundary Measurement

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Image Reconstruction in Electric Field Tomography (EFT)

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Abstract— The electric field tomography is relatively new imaging method applicable for biomedical applications. It uses interaction of alternating electric field with the conducting media to obtain information about the spatial distribution of its conductivity without electrical contact with the object. The method is based on the Maxwell-Wagner relaxation phenomenon, i.e., finite relaxation time of the nonequilibrium free charges in the conductor. This phenomenon leads to the phase shift of the alternating electric field outside the object depending on its internal electrical properties and geometry. Measuring such phase shifts using multiple transmitting and receiving electrodes enables to reconstruct internal structure of the object. Mathematically such reconstruction procedure consists of solving the inverse problem for Laplace equation with inhomogeneous complex permittivity. While this inverse problem is ill-posed and nonlinear in general, fast and robust linearized algorithms are most interesting for the practical system implementation. Forming of the appropriate reconstruction matrix converting measured phase shifts into image is possible in various ways. One of them is single step regularized Gauss-Newton method. Another is least squares optimization using extensive training data sets comprised of different distributions of properties and corresponding simulated results of measurement with appropriate noise added. Such approach is known as linear artificial neural network also. One of the popular heuristic algorithms is back projection. It is based on known spatial localization of the most sensitive areas for each transmitter-receiver pair. We have implemented successfully the back projection method for EFT taking into account that sensitivity is localized near the line of electric field connecting the active and sensing electrodes. Corresponding results of numerical simulation and applying the algorithm to the experimental data are demonstrated. The linear neural networks are considered also as very promising for EFT image reconstruction.

Overview of Electric Field Tomography Experiments in Russia

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Abstract— The paper introduces EFT operational principal briefly and overviews EFT experiments in Russia.

EFT based on the Maxwell-Wagner relaxation phenomenon accompanying redistribution of nonequilibrium free charges carriers inside the inhomogeneous conductive object. It is a new kind of quasistatic electro-magnetic tomography suitable for contactless imaging of biological objects.

The first single-channel measuring EFT system and set of experiments are discussed. Single channel experiments proved EFT theory and shown possibility to obtain data required for EFT realization.

The first multi-channel measuring system for EFT is described. Experiments on imaging of a test objects with different geometry and electrical properties are presented. The first EFT images obtained experimentally are given and discussed.

Using Memristive Elements for Modeling Electrical Properties of Biological Tissue

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Abstract— The memristor was predicted by Leon O. Chua to exist on purely theoretical grounds many years ago [1], but was not realized in the laboratory as a physical, electronic nano-component until 2009 [2]. The memristor is treated as an elementary passive circuit element, complementing resistors, coils, and capacitors (RLC), whose memristance $M(q) = d\phi/dq = v/i$ is defined by how the magnetic flux $\phi = \int v(t)dt$ responds to the charge $dq = idt$ transported by the electrical current $i(t)$.

Later the concept was expanded to memristive systems [3], which are generalizations of the memristor concept where the memristance is controlled by a number of state variables. Furthermore, in 2009 the theory was further expanded by Di Ventra et al. to memcapacitance and meminductance [4].

We show that electro-osmosis in human sweat ducts is of memristive nature and that memristors therefore will be important when modeling electrical properties of human skin. We also show that dielectric dispersion in biological tissue is of memcapacitive nature and that nonlinear phenomena probably play a significant role in the overall electrical properties of biomaterials.

Numerical Reconstruction of Perfectly Conducting Inclusions from One Electrostatic Boundary Measurement

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Abstract— Electrical Impedance Tomography (EIT) aims to reconstruct inhomogeneities or inclusions in the interior of a medium based on current and voltage measurements at the boundary of the medium. In many practical applications of EIT, the efficiency of the employed numerical inversion scheme is an essential parameter.

The inversion methods typically evaluate an indicator function in order to estimate whether or not a given point is in the interior of the sought inclusion. The so-called sampling methods do not assume any à priori knowledge about the boundary condition valid at the inclusion boundary, but the evaluation of their indicator functions can be numerically expensive. On the other hand, decomposition methods express the solution of the Laplace equation in the medium in terms of layer potentials and estimate the inclusion using boundary value error minimisation. However, matching the sources in the potentials with the measured current or voltage at the medium boundary can be numerically costly.

We describe a novel method for the reconstruction of perfectly electrically conducting inclusions in arbitrary homogeneous, simply connected media of finite conductivity and with sufficiently smooth boundary. Similarly to the decomposition methods, our approach is based on a boundary layer representation of a solution of the Laplace equation in the medium, and it uses à priori knowledge of the boundary condition satisfied at the interface between the inclusion and the medium. However, both of these developments occur at the analytic stage only, and the actual numerical computation involves neither forward-model sources nor boundary-error minimisation. The method requires inclusions to be placed relatively close to the boundary of the medium, and it is well-suited for detection of small inclusions and for detection and partial shape estimation of large inclusions.

We give a mathematical justification for the indicator function used in the inversion method. Also, we illustrate the performance of the method using several numerical examples involving different medium geometries, as well as single and multiple inclusions of different shapes and positions within the medium. Finally, we compare the efficiency and accuracy of the method to a decomposition scheme based on the Method of Auxiliary Sources.

The Impact of Model Mismatch Errors on Magnetic Induction Tomography Inverse Problem

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Abstract— Magnetic induction tomography (MIT) is a non-invasive and non-contact imaging modality that attempts to reconstruct the internal conductivity distribution of the human body. It promises to facilitate diagnosis of several physiological disorders such as edema or internal hemorrhage and has the potential to be used for continuous monitoring of physiological uids. Several features of the device such as high-speed data acquisition, portability and comparably inexpensiveness make the proposed modality attractive.

In MIT, an array of coils is used to induce eddy-currents inside the body and the magnetic fields are recorded outside using an array of magnetic sensors. The corresponding inverse problem is defined as the reconstruction of conductivity distribution from the measured magnetic fields and is generally stated based on the minimization of the Euclidean norm of the data misfit term. Therefore, small differences between the modeled and true coil geometry induce errors in the data misfit and generate artifacts in images. In this study, we performed a simulation study to analyze the impact of modeling errors on measured data and corresponding conductivity reconstructions.

For the analysis, we considered two different cases of coil geometry distortions: the displacement of coils from ideal positions and rotation of coils. We generated synthetic data by using a typical 16-channel MIT system coil arrangement. We indexed the worst receiver channels in terms of susceptibility to distortion errors in data and in the corresponding reconstructed images. It was found that slight geometrical distortions of the coils may cause significant deviations in the data considering local and small perturbations in conductivity. It was showed that the imaging artifacts appear on the proximity of the boundary of the conducting object.

A Software Based Framework for Estimating Patient Displacement in Magnetic Induction Tomography

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Abstract— Magnetic Induction Tomography (MIT) is a contactless, inexpensive and non-invasive technique for imaging the conductivity distribution inside volume conductors. Time-difference imaging can be used for the monitoring of patients in critical care. This includes monitoring of cerebral strokes and breathing (aeration and ventilation of the lung), as well as continuous screening of oedema. However, MIT signals are much more sensitive to body movements than to the conductivity changes inside of the body. This is because small movements during MIT measurements can overwhelm the signals of interest and cause significant image artefacts. Thus, it is crucial to accurately estimate and factor body movements into image reconstruction. Movement estimation is nonetheless a challenging problem due to 3 possible translations (along x, y and z axis) and rotations which can cause significant signal magnitude changes as well as phase shifts.

Methods: We proposed algorithmic methods for identifying and estimating object movements from simulated MIT data prior to the image reconstruction step. A simulation was performed based on a 16 channel MIT system where a finite-difference based MIT software package was used to (i) generate reference data without a target and movement, and (ii) simulate whole tank movement with a target placed close to edge of the tank. The homogenous tank (radius of 13.5 cm and height of 20 cm) has the conductivity of $1\,\mathrm{Sm}^{-1}$, and the small cubic target has the conductivity of $3\,\mathrm{Sm}^{-1}$. The movement was estimated using frequency domain analysis (FFT and Wavelet), and statistical approaches (Independent Component Analysis (ICA)) that used training data on various displacements. Once movements are identified, images are reconstructed by (i) minimizing movement artefacts for small movements; (ii) compensating for the movements if these are accurately estimated, or (iii) taking a new MIT measurement if movements are too severe.

Results: Results show that movements of 1% of the radius of the tank cause image blurring but the artifacts can be minimized by regularization. Higher movements totally distorted images which require artifact compensation or acquisition of new measurements.The percentage errors for FFT based movement estimation were 35%, 0.3% and 6% for a displacement of 1% (1.3 mm), 5% (6.7 mm) and 10% (13.5 mm) respectively where the displacement was chosen relative to the radius of the tank. ICA and wavelet approaches also produced similar results to the FFT based approach. It was also found that the accuracy of movement estimation was found to be related to the size of the background in real measurements.